

MONTHLY PROGRESS REPORT

"HTS Josephson Technology on Silicon with Application to High Speed Digital Microelectronics"

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Summary of Progress

Task 1: Josephson junction fabrication and Testing

This is the most critical task in the program. Progress has been held up by an unanticipated failure of the electron beam writing device at Stony Brook. The instrument had not been working for much of the last three months. The system is now up and working, and an attempt was made to fabricate junction from an HTS film on a silicon substrate.

The film had good superconducting qualities as determined by resistance Vs. temperature measurements at AFR and was shipped to Stony Brook for junction fabrication. The film was etched into three bridges approximately four microns across and measured again for resistance Vs temperature. Unfortunately, the no supercurrents were detected. Two of the junctions were highly resistive at all temperatures, and the third showed a partial transition at 90 K, but retained a residual resistance of 400 Ω below the superconducting transition temperature of the film. The R Vs T for the bridge is shown in Fig. 1. The rest of the unpatterned film was remeasured using silver paste dots as contacts to determine if the entire film was bad. We found that the film was still superconducting with a T_c of 89 $^{\circ}\text{C}$. From this we conclude that either the patterning process damaged the bridges, or that the film was sufficiently non-uniform that the bridge was traversed by some completely non-superconducting regions or grain-boundaries.

We do not believe that this problem will persist. An earlier film of YBCO on silicon was successfully processed into working Josephson junctions in April of 1994. The Josephson behavior of this device were established by measuring microwave induced Shapiro steps, magnetic modulation of the critical current. These results are shown in Figs. 2 and 3.

During the next month, now that the electron beam writer is running, we will send a significant number of new films to Stony Brook and fabricate more junctions.

Task 2: RSFQ Modeling and Design

Due to a computer printing problem in last months report, the equations were absent from the Task 2 write-up. Here is a revised version of that work.

All RSFQ logic elements depend on maintaining a balance between the Josephson inductance and the SQUID loop inductance such that $2\pi I_c L \approx \phi_0$, where $\phi_0 = h/2e$ is the elementary flux

quantum. ϕ_0 is equal to 2.07 mA-pH in practical electrical units. The exact relation between I_c and L is determined by design simulations of a particular logic gate. To ensure that thermal fluctuations do not cause bit errors, the thermal energy unit $K_B T$ must be small compared to the energy scale of the Josephson junction, which is given by $E_J = \phi_0 I_c / 2\pi$. Setting $K_B T = 10 E_J$, we get the result that thermal fluctuations limit the minimum critical current I_c to be at least 38 μA at 90 K. In order that the inductance's can effectively store and process single flux quanta properly, the SQUID inductance is therefore required to be at most $L = \phi_0 / (2\pi I_c) = 8.6$ pH. Typical inductance numbers for coplanar transmission lines are of the order of 0.5 pH per micron. This implies that careful device design simulations and circuit layout will be required for success. Achieving control over the inductance requires that proper account be taken of all sources of inductance in the SQUID. For this reason, the analysis of the SQUID results reported in report 0001AB was continued. Assuming that the SQUID modulation depth is entirely due to inductance and not critical current nonuniformity, we found that the low temperature London penetration depth $\lambda_L(0)$ was 370 nm. This is approximately two times higher than what is expected for high quality films. The results under discussion were obtained from films grown by the post-annealed barium fluoride process. It is not surprising that these post-annealed films were of lower quality than films grown in-situ by pulsed laser. If our films on silicon are comparable to PLD grown films on oxide substrates, then we should see approximately a two-fold decrease in penetration depth and a concomitant four-fold decrease in parasitic inductance. If this is born out, then we expect that functional RSFQ logic elements will be possible even with films as thin as 60 nm.

Parasitic Inductance - Very thin film transmission lines have two components to the inductance. First, is the more familiar geometric inductance, which arises from the energy stored in the magnetic fields surrounding and penetrating the conductors. Second, is the kinetic inductance, which is often considered a parasitic quantity. The kinetic inductance arises from the kinetic energy of the current carrying cooper pairs. For very thin films, the sheet kinetic inductance is given by λ_L^2 / t where λ_L is the London penetration depth and t is the film thickness. Using 370 nm for λ_L at low temperatures and $t = 500$ nm, we obtain a parasitic kinetic inductance of 0.04 pH/ at low temperatures. As T approaches T_c , the London penetration depth diverges, and the parasitic inductance increases as well. All this implies that thicker films are more desirable from an inductance point of view, and that methods to allow thicker films on silicon would be extremely helpful. At present, film stress provides the main limitation to film thickness. This is why we are examining the roles of new buffer layers in reducing film stress, (see last months report).

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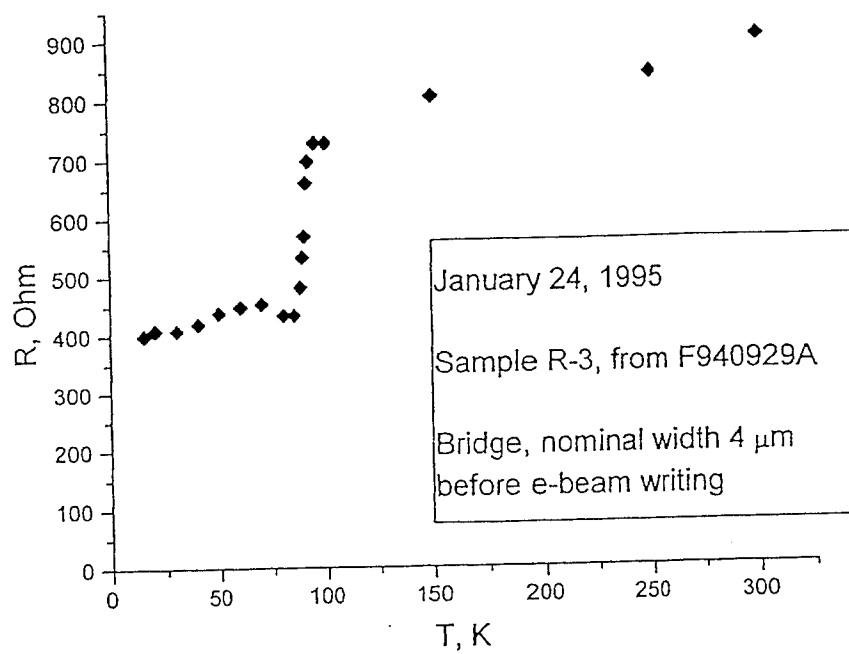


Figure 1. R Vs T curve for a microbridge patterned from a YBCO film on YSZ buffered silicon.

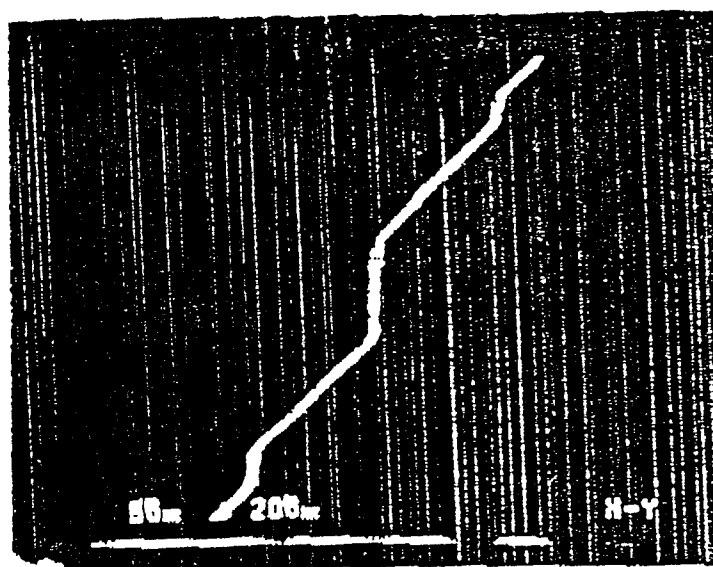


Figure 2. Microwave induced Shapiro steps in the current voltage characteristic of an E-beam modified Josephson junction fabricated from YBCO on YSZ buffered silicon. The data were measured at 52 K.

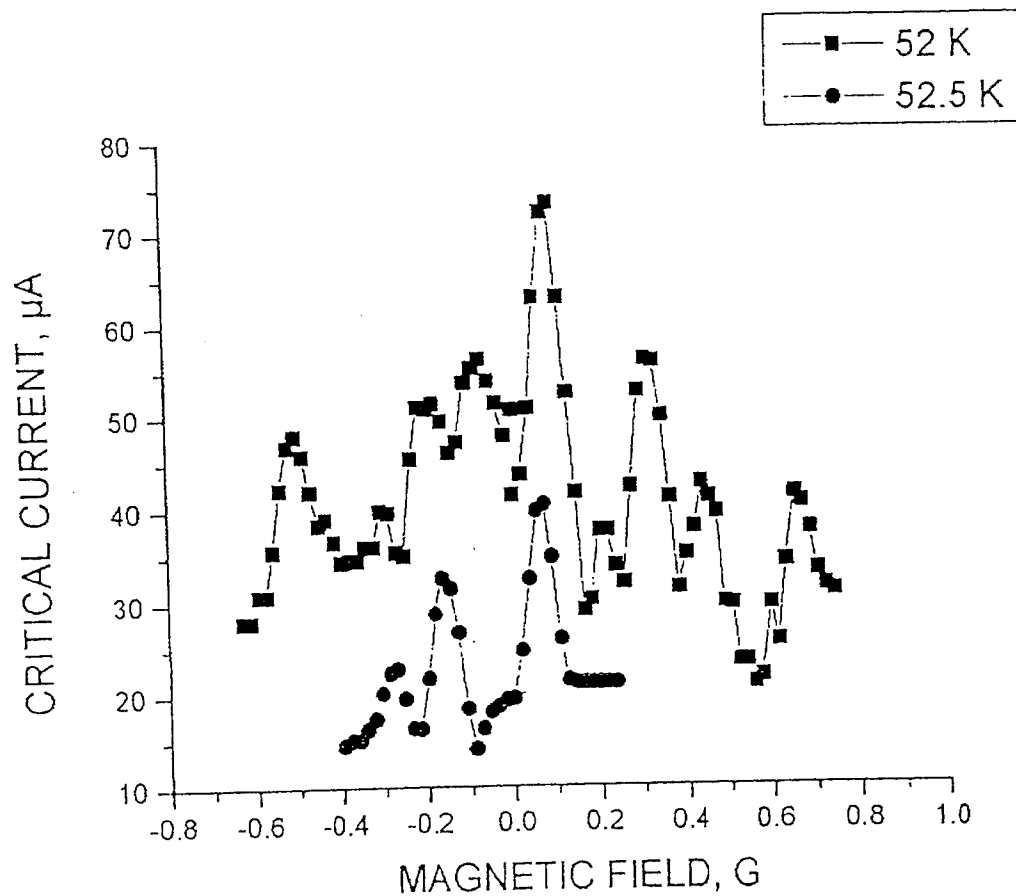


Figure 3. Magnetic field dependence of the critical current of an E-beam modified Josephson junction fabricated from YBCO on YSZ buffered silicon.